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Nondestructive evaluation of multilayered structures using horizontal shear modes generated by an electromagnetic acoustic array transducer

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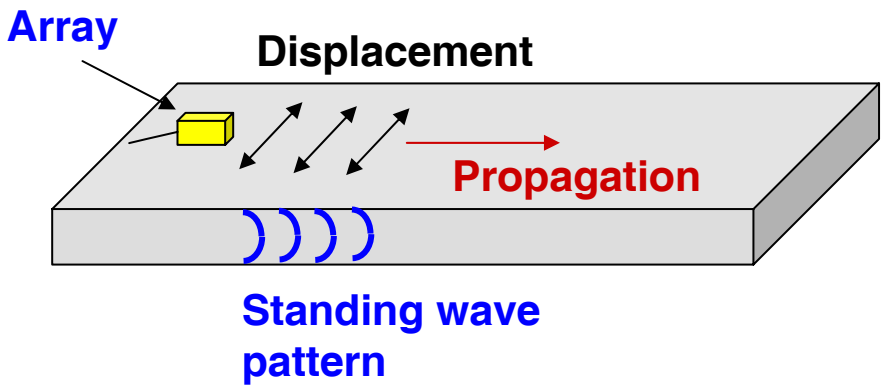
Horizontal Shear Guided Wave Modes

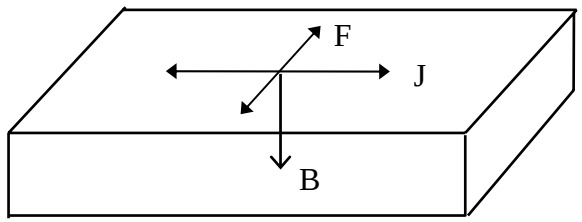
- λ ~ thickness
- Displacement is transverse to propagation direction
- Standing wave pattern across the thickness is unique to each mode
- Many modes are possible
- Mode propagation is dispersive in nature due to reliance on boundaries for propagation
- Propagate long distances (tens of feet in a plate)
- Can efficiently inspect large areas as well as inaccessible areas

Horizontal Shear Modes



Electromagnetic acoustic array transducer generates modes via a periodic Lorentz force

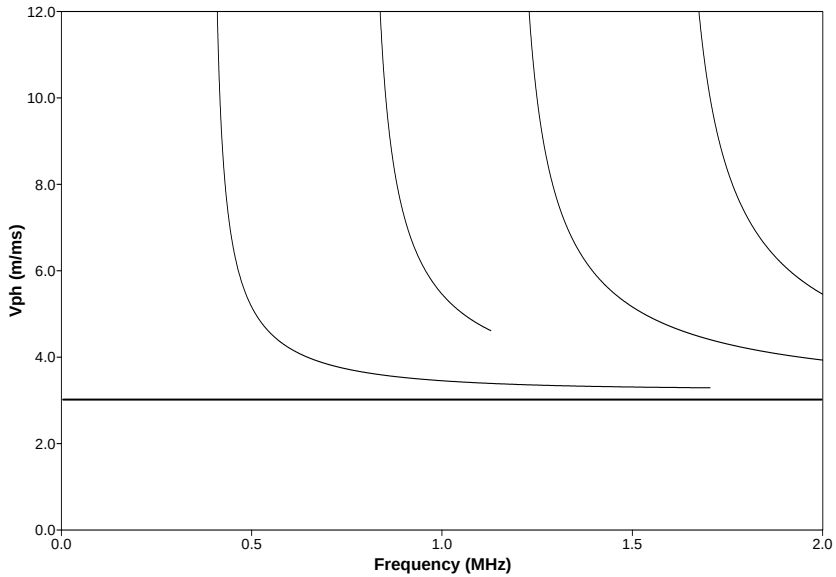
- Lorentz force is generated by the cross product of electrical current and the external magnetic field created by the permanent magnet
- Periodic permanent array magnet is used to generate a particular wavelength
- No couplant is required
- Frequency is swept to generate various modes
- Permanent magnet arrays of various spacings are used to obtain different wavelengths



Multilayered media have dispersion curves that show all the possible horizontal shear modes

- **Phase velocity dispersion curves depend on material properties, thicknesses, geometry, and boundary conditions**
- **Dispersion curves establish all modes of guided wave propagation**
- **Horizontal shear modes are shown, but Lamb type modes are also possible**
- **Air and liquid loading will not dampen modes propagating in a structure**
- **Group velocity dispersion curves are calculated to determine the speed of the mode**

Phase velocity dispersion curves for Al-Epoxy-Steel structure



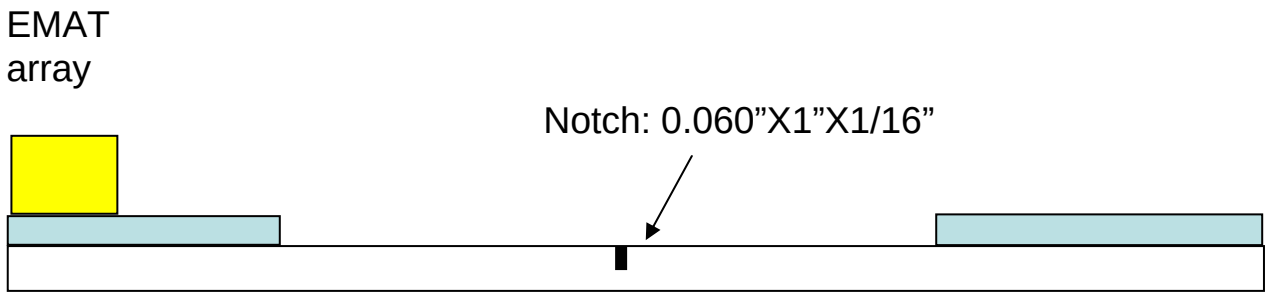
Multilayered structures were constructed with flaws of various sizes for experimental study

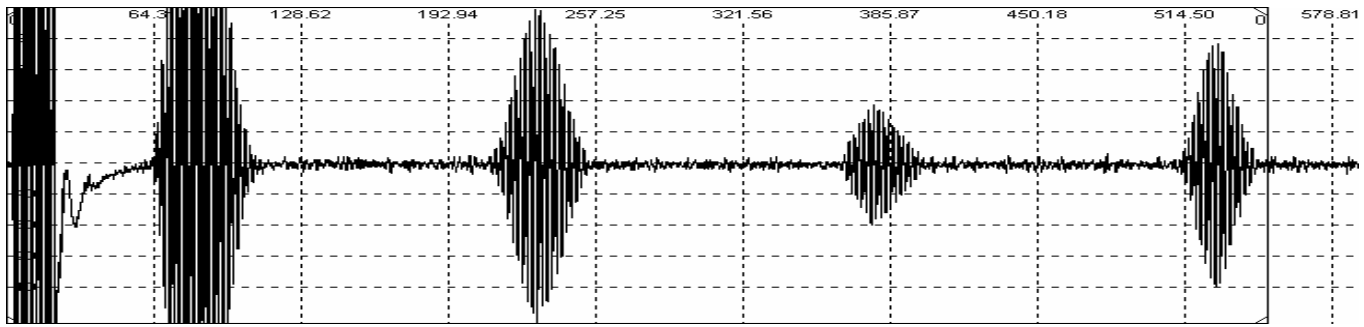
Layer	Material	Thickness (in.)
1	Al	0.125”
2	Epoxy	0.010”
3	Steel	.125”

Flaw size table

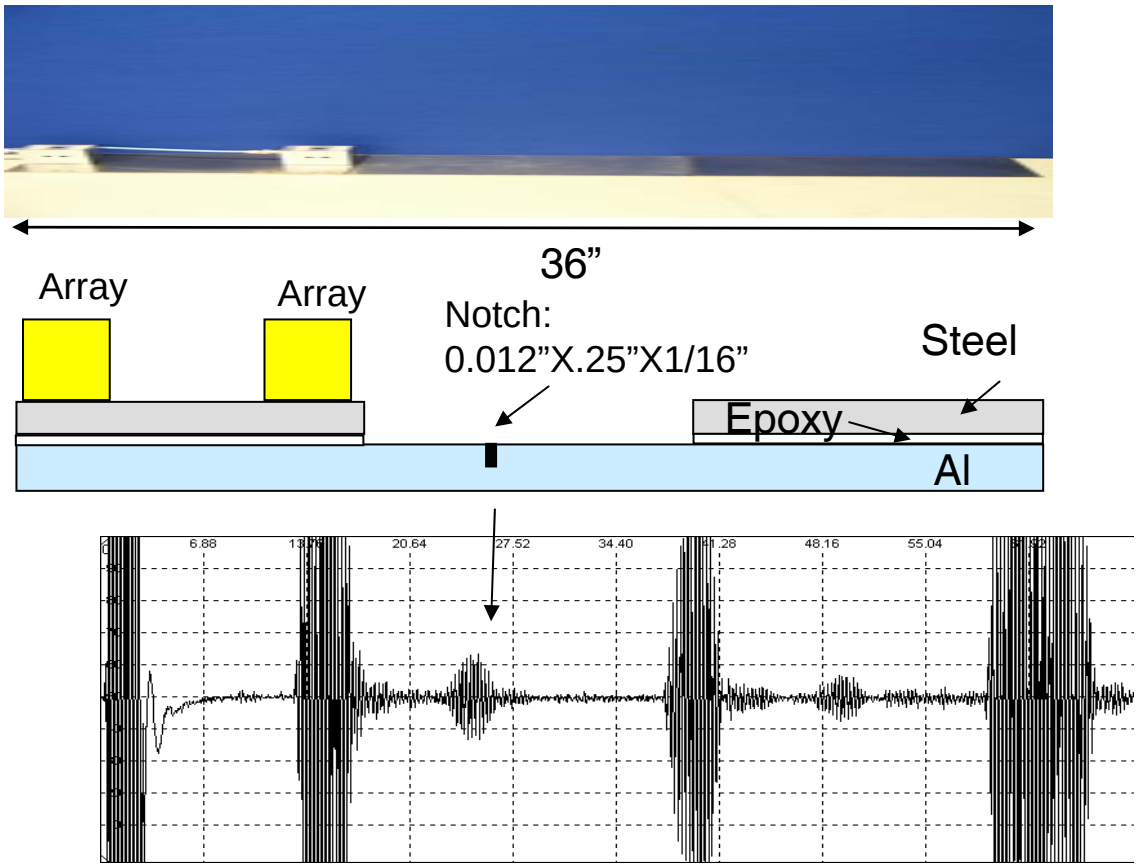
Flaw Depth (% thru-wall)	Length (in.)	Width (in.)
10%	0.25”	.031”
20%	0.375”	.031”
30%	0.50”	.31”
50%	1”	.31”
100%	1.5”	.31”

A sample RF waveform shows the detection of a 50% through-wall notch by a horizontal shear mode at 510 kHz

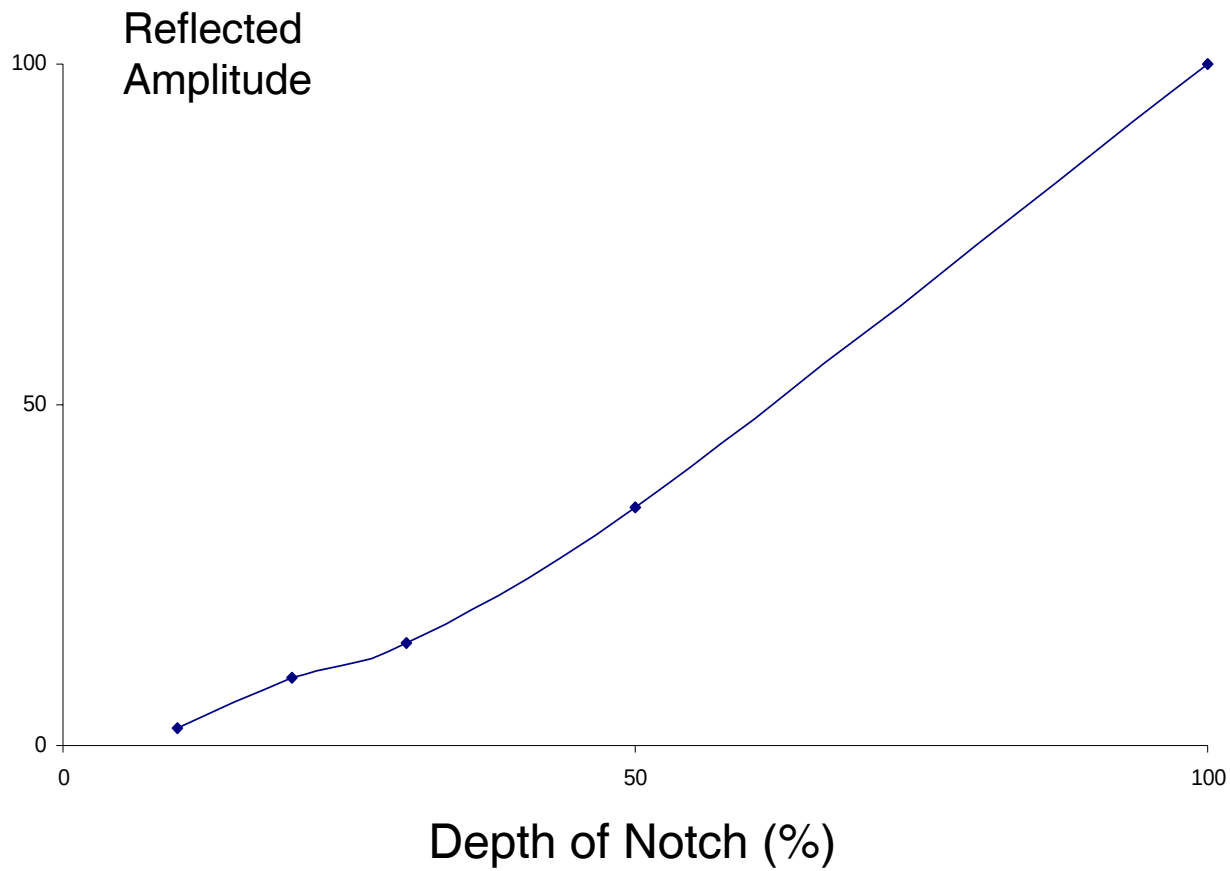




The smallest size flaw (10%) was detected with good signal-to-noise at 510 kHz



A plot of the reflected amplitude of the lowest order horizontal shear mode shows a linear relationship



Cross-sectional area was reduced as depth was decreased.

Concluding Remarks

- Better resolution was achieved with a mode at 510 kHz
- As frequency was lowered, SNR (signal-to-noise ratio) decreased due to weaker reflection from the flaw
- At frequencies above 510 kHz, SNR again was decreased to the presence of higher order modes
- Sensitivity was maximized by utilizing the lowest order horizontal shear mode at a frequency times thickness product that just below the cutoff of higher order modes